Target Support Facility for a Solid Target Neutrino Production Facility

Phil Spampinato

Joel Chesser

Tony Gabriel

Franz Gallmeier

John Haines

Dick Lillie

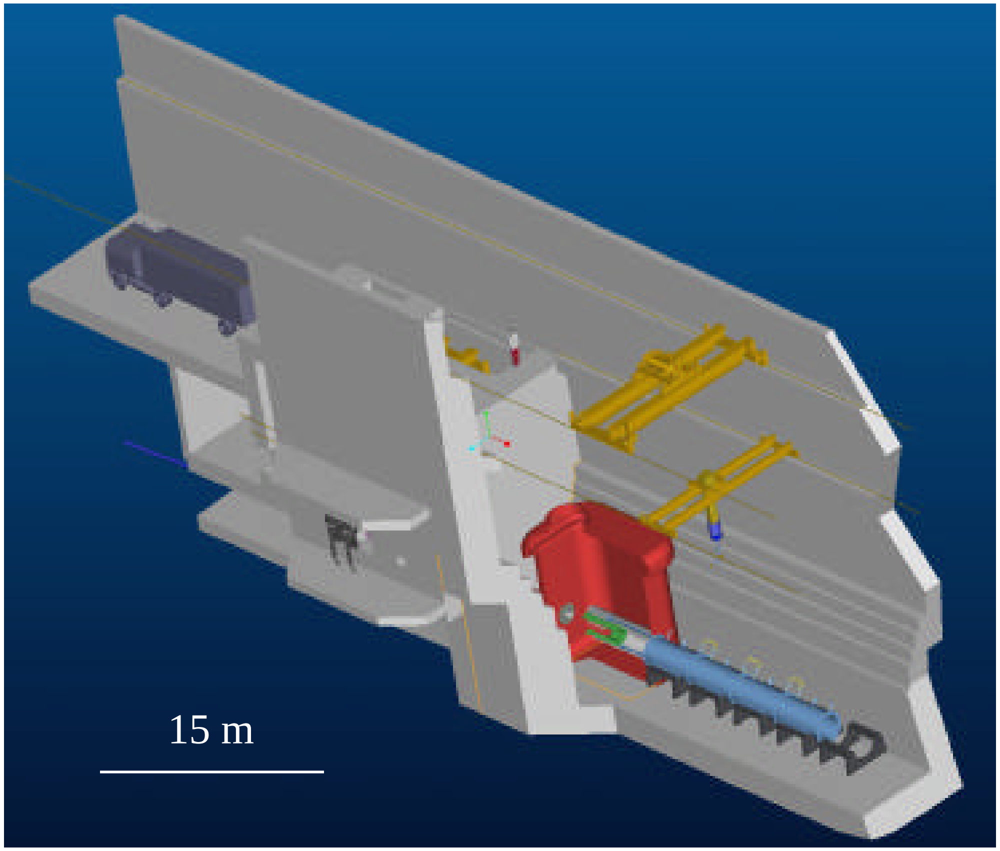
Tom McManamy

Operated by UT-Batelle

This work is part of the "**FNAL Feasibility Study of a Neutrino Source Based on a Muon Storage Ring**"

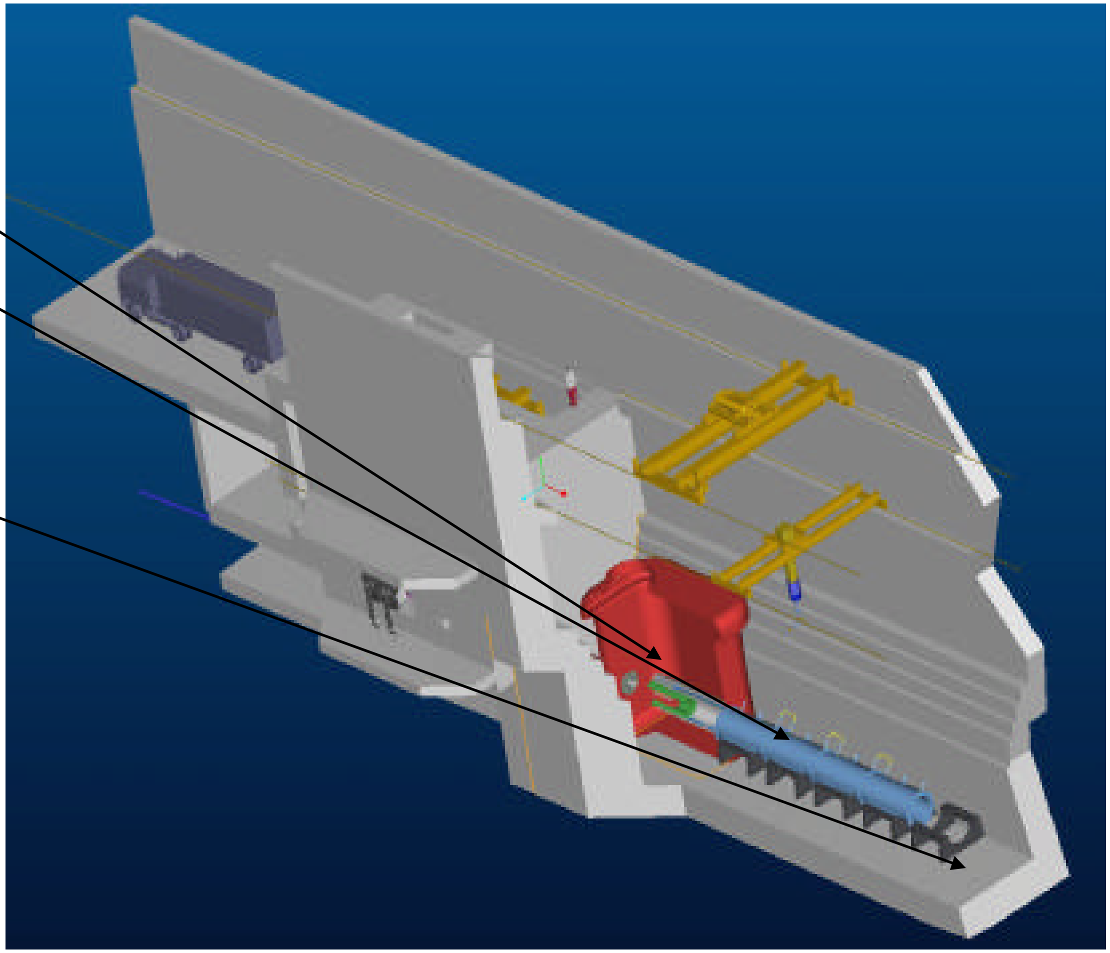
Outline

- Overall facility
- Design requirements & assumptions
- Target analysis/design
- Proposed R&D
- Decay channel
- Shielding
- Radiation handling
- Cost



Features of the Target Support Facility for the Fermilab Study

- Graphite target, He vessel
- Hybrid solenoid system *(National High Magnetic Field Laboratory)*
- Decay channel
- Nuclear shielding
- Radiation handling



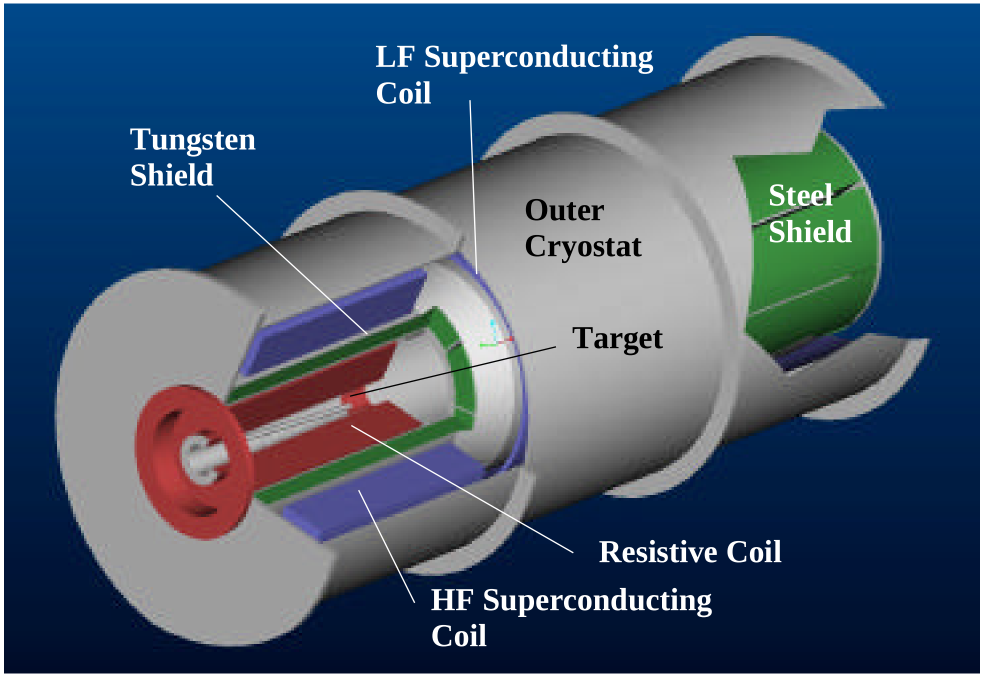
Design Requirements/Assumptions

- 16 GeV, 4 MW beam on target
- Operating availability 2 x 10^7 sec/yr *(therefore, life-limited components are modular)*
- Dose for personnel access in crane hall <0.25 mr/h

Component	**Expected Lifetime**	**Replacement Time**
Target	3 mos	6 days
Target + Bitter Coil	6 mos	7 days
Target +Bitter Coil + PBW	1 yr	8 days
PB Instrumentation	1 yr	5-7 days
Beam Dump	5 yrs	1.5 mos
High Field S/C Coils	>20 yrs	9-12 mos
Low Field S/C Coils	>20 yrs	9-12 mos

The Target Region is in a He Containment Vessel that Minimizes Air Activation and Target Evaporation

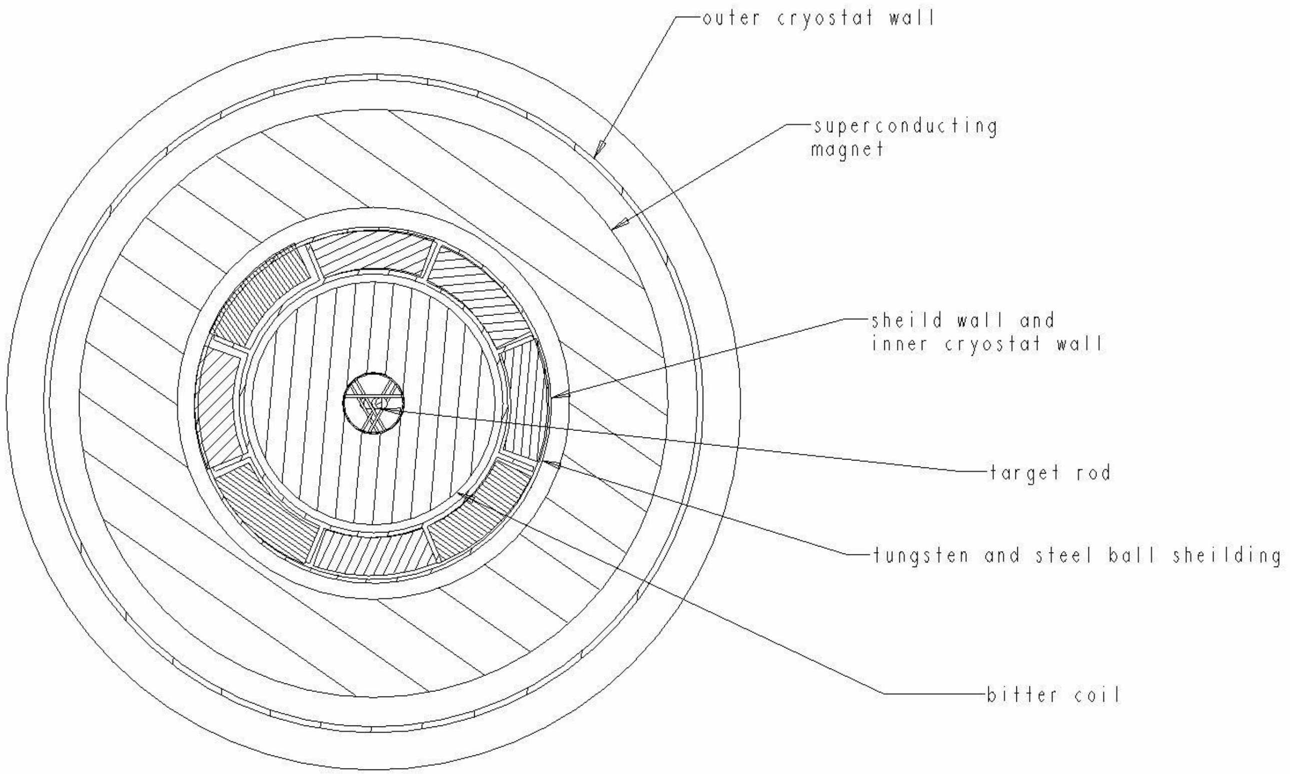
- Target: 1.5 cm diam x 80 cm length *(per Mokhov)*
- High field solenoid: 8T Bitter, 12T Ni_3Sn
- Low field: 1.25T NbTi
  - coils are arranged in 4 m common cryostats to self-react magnetic forces
- Magnet shield: W & steel
- Bulk shield: 4.5 m steel & 2 m steel in decay channel



MODULAR ARRANGEMENT OF COMPONENTS IN THE TARGET REGION

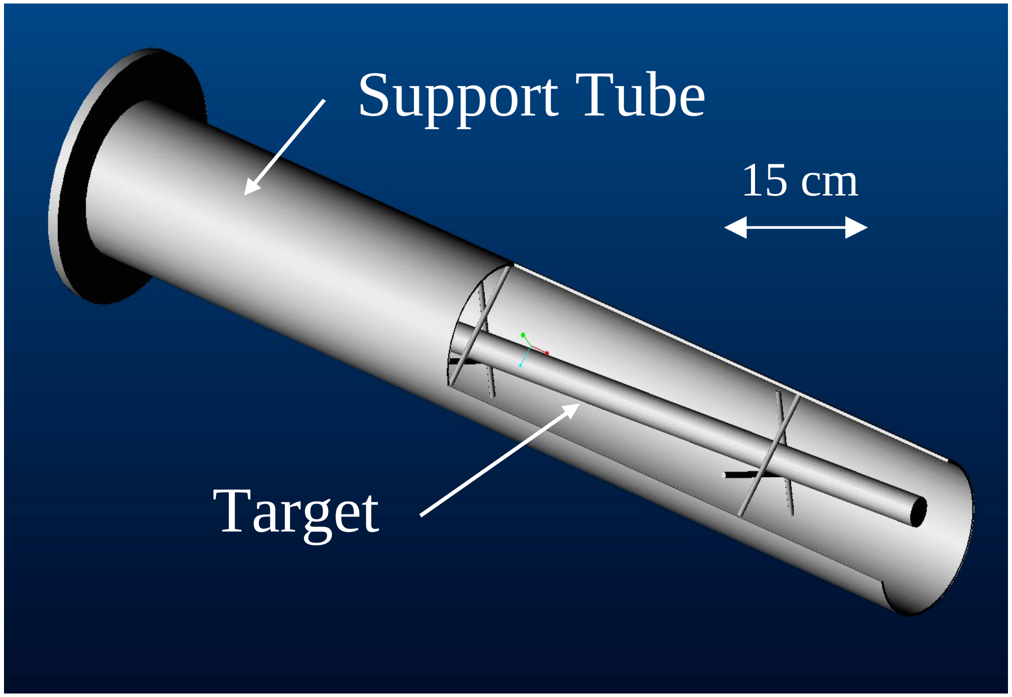
Target Region (cont.)

- A section through the target shows the arrangement of modules within modules



The Graphite Target is a Passively Cooled Rod-like Structure within a Support Tube

- It is coaxial with the proton beam, but 50 milli-radians to the magnetic axis of the decay channel (*Mokhov*)
- Supported on graphite spokes
- Radiates to a water-cooled stainless steel support tube (15 cm diam)



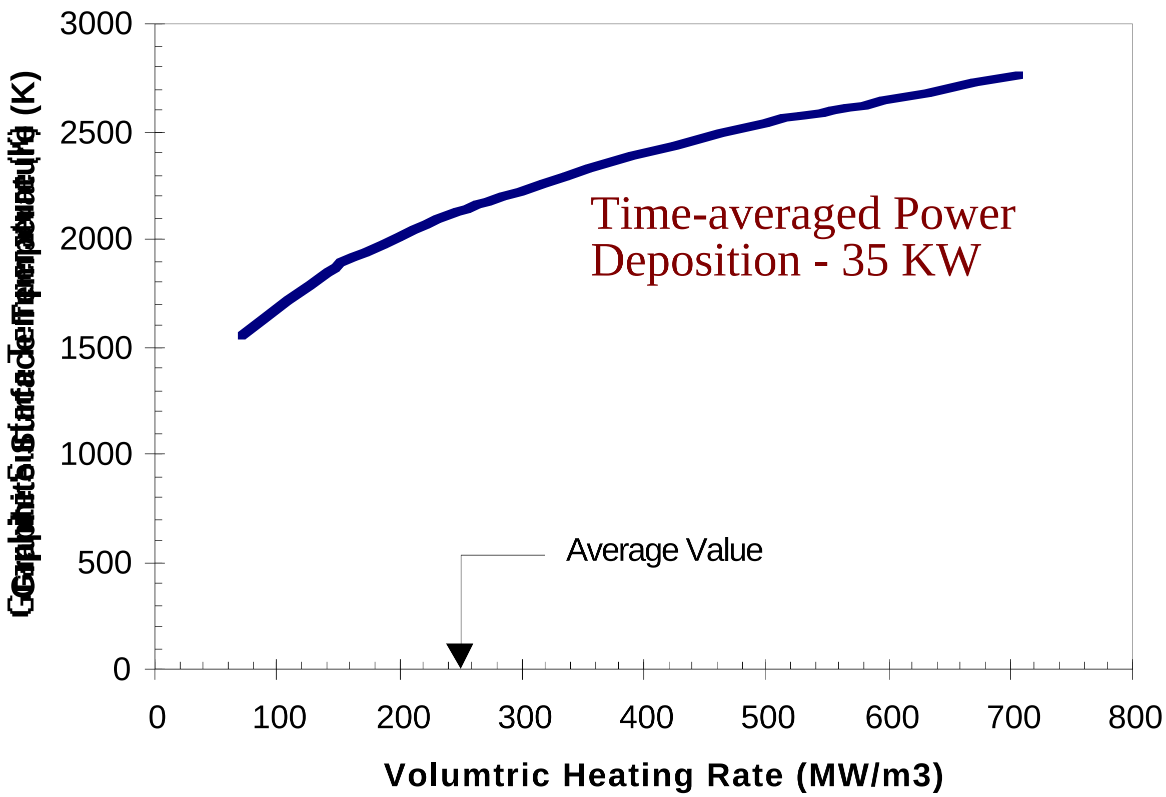
Target (cont.) - Stress

- Preliminary thermal and structural analyses were performed to address feasibility of the concept and identify key issues
- Per Mokhov's results, time-averaged power deposition (1.5 MW beam) = 35 KW
  - volumetric power deposition is 250 MW/m^3 (assumed uniform along axis)
  - target surface temperature 1850^{0}C
  - temperature at center 1925^{0}C
  - thermal stress 5 MPa < 30 MPa

Muon Collaboration

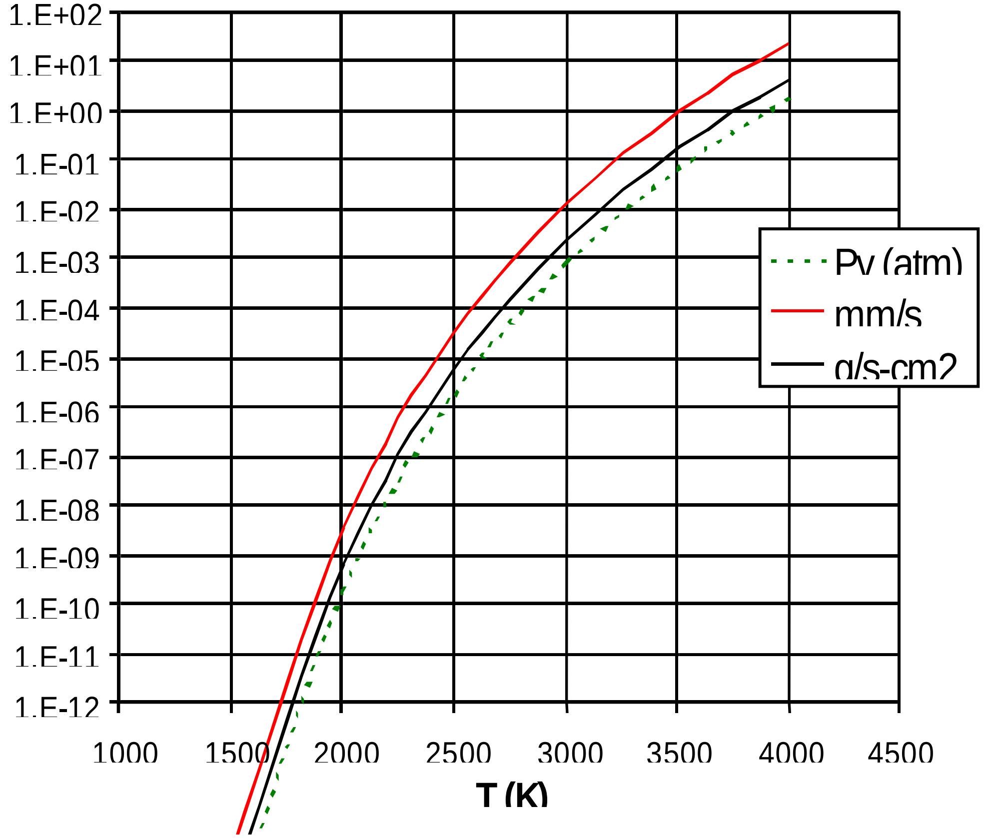
Target - Stress (cont.)

- If peak power distribution is 2X average, surface temperature = 2260^{0}C, stress = 10 MPa



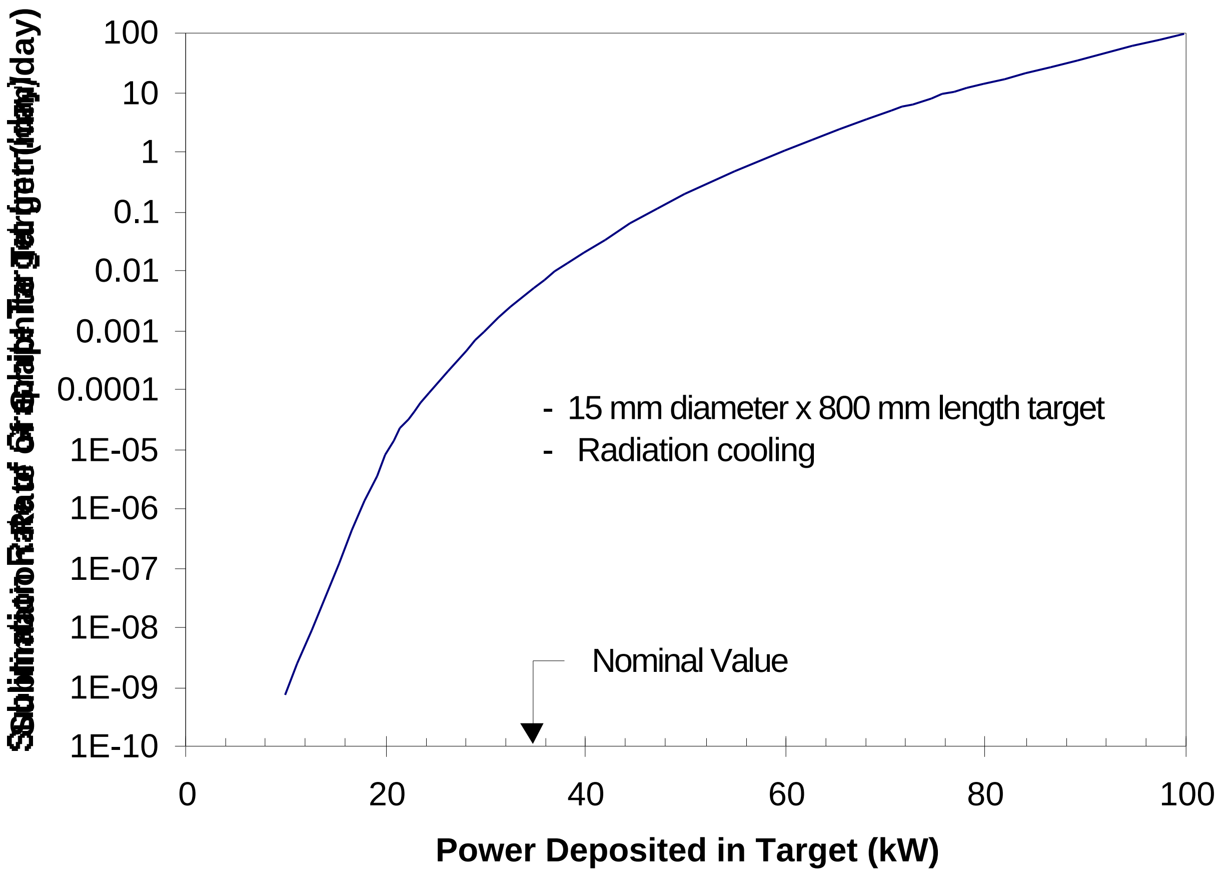
Target (cont.) - Sublimation

- Sublimation in a perfect vacuum is temperature sensitive; (provides a conservative estimate compared to He data)
- At 250 MW/m^3 (1850^0 C surf.), recession rate = 5 μm/d



Target - Sublimation (cont.)

- at 2X the average power deposition, recession rate = 5 mm/d



Target (cont.) - Issues

- These results support the feasibility of using a radiatively cooled graphite target, but also demonstrate the need for additional work to:
  - predict axial power deposition
  - determine temperature distribution with realistic modeling and radiation heat transfer
  - perform tests to determine sublimation rate in a He environment over a practical range of pressures

Target Issues (cont.)

- Other Issues For Evaluation
  - Examine irradiation database for graphite since radiation damage may be the life limiting mechanism
  - Evaluate use C-C composites which incorporate carbon fibers within a graphite matrix
    - for improved thermal-mechanical properties and increased resistance to irradiation damage
    - to develop a detailed design for supporting the target within a water-cooled support tube that allows free expansion of the target as it heats up

Proposed R&D

- Near term R&D to address material issues is $64K

Near Term R&D Tasks for the Graphite Target (1.5MW Design)

1. Assess commercially available graphite-composite properties for candidate target materials. ($2K)
2. Develop a neutronics model for heating distribution (energy distribution) in the target. ($5K)
3. Develop a neutronics model for heating distribution and multiple scattering effects in the proton beam window. ($2K)
4. Develop a finite element model for temperature and stress distributions, and deflections. ($6K)
5. Develop a test plan, design and assemble equipment for sublimation tests under high temperature conditions in a helium environment: assuming that test equipment is available, do benchmark tests in vacuum; exploratory tests would proceed to measure sublimation rate and determine the effect of He pressure and purity. ($21K)
6. Do thermal shock tests using ATJ graphite; assess material survivability. ($5K)
7. Develop the design details for the radiatively cooled target, including target rod supports, the water-cooled support tube, utility connectors, and remote handling approach. ($23K)

Proposed R&D (cont.)

- Longer term R&D to address material survivability issues and design issues is $387K

List of Additional (Longer Term) R&D Tasks

1. Complete the sublimation tests under target operating conditions. ($32K)

2. If a suitable carbon-carbon composite material is found that has insufficient irradiation data, test for neutron/gamma irradiation survivability at ORNL's High Flux Isotope Reactor. ($120K)

3. Construct and test a full scale prototype target; assess the geometric integrity of the support structure and the target rod (fabrication and alignment issues); assess support schemes for graphite wire, silicon carbide, …, assess remote handling features. ($85K)

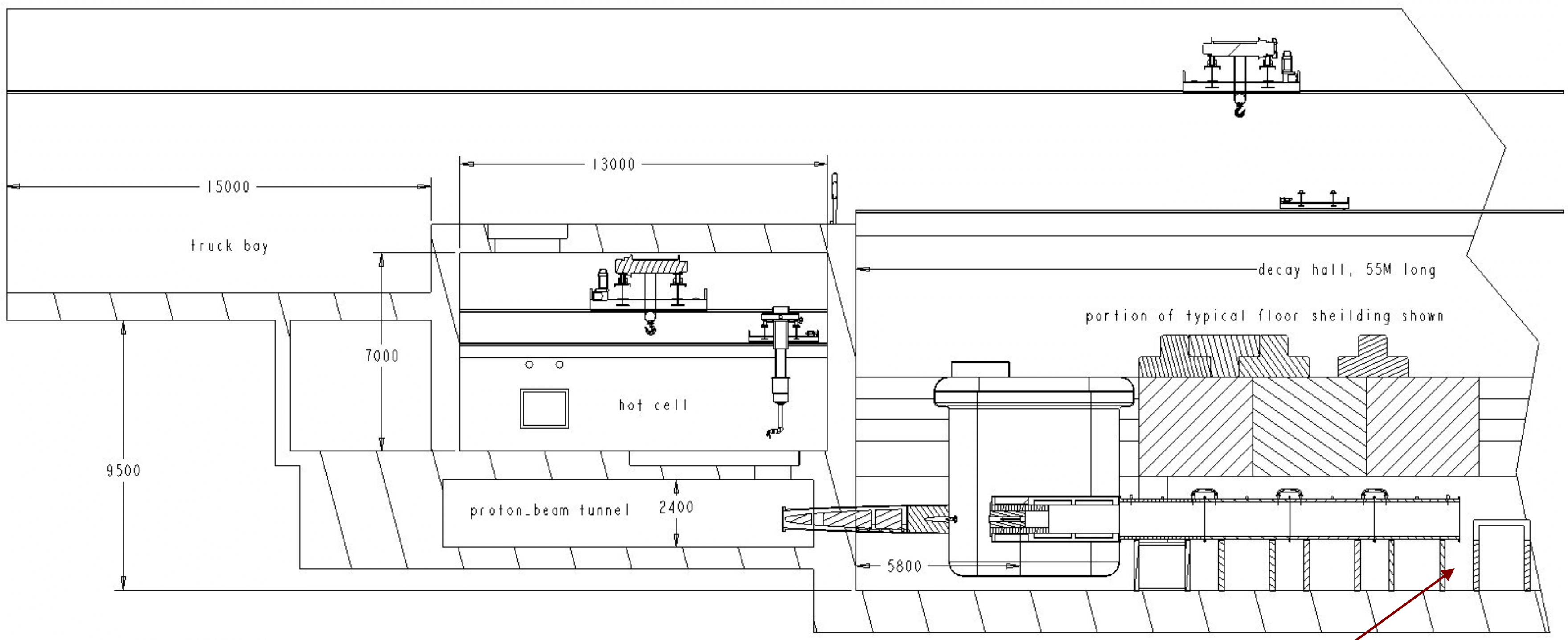
4. Develop a preliminary design of the target beam stop located at 5.5<Z<6.5 m). ($26K)

5. Develop a full scale mock up of the target region (-120<Z<140 cm) using low cost materials; demonstrate access and remote handling for replacing the target and Bitter coil; assess downtime. *(Note: Robotic facilities and remote handling equipment in use by SNS are available at ORNL at no added cost.).* ($92K)

6. Develop a proton beam window mock up; demonstrate remote removal of cooling and diagnostic connectors; demonstrate window replacement; assess downtime. *(Note: Robotic facilities and remote handling equipment in use by SNS are available at ORNL at no added cost.)* ($32K)

Decay Channel

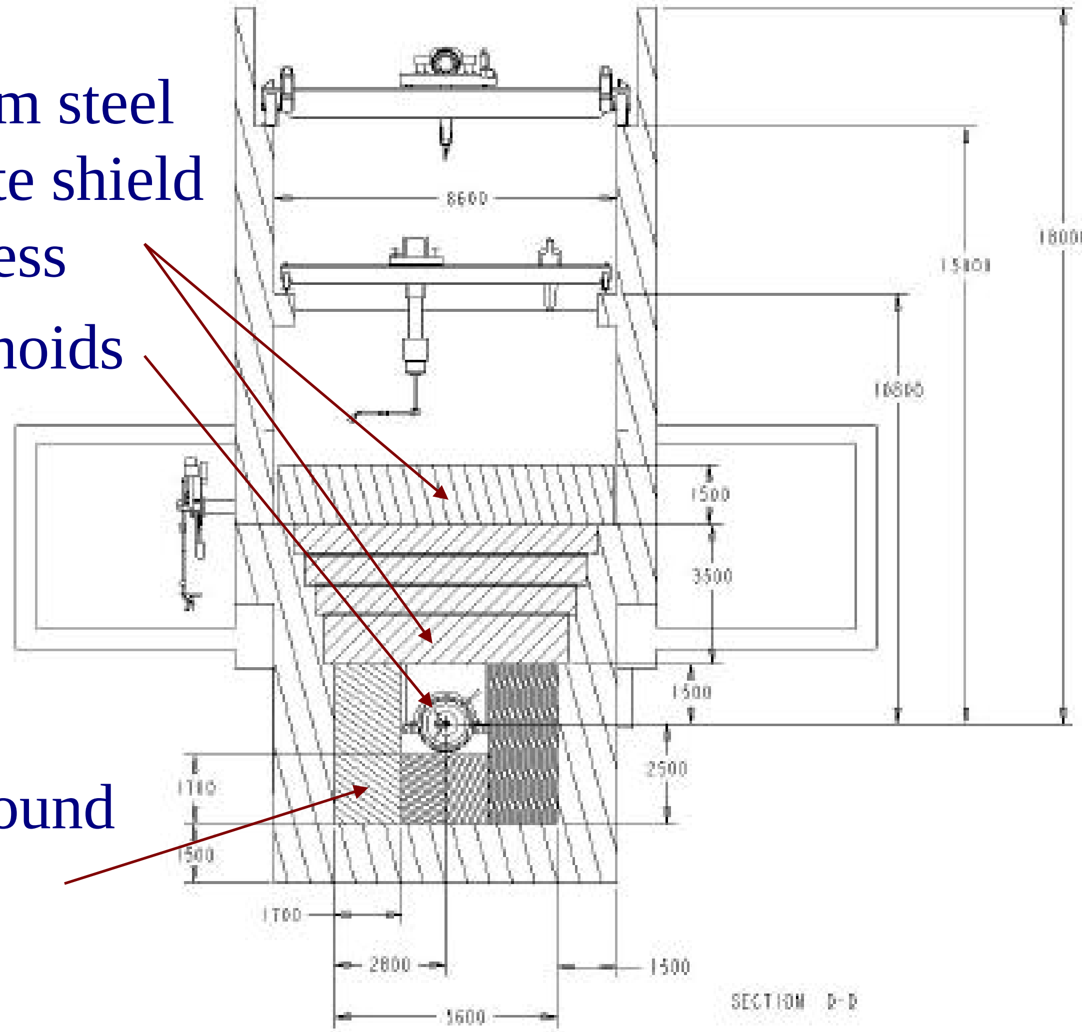
- 50 m long, located under crane hall; contains twelve 4 m LF cryostats
- LF coils have 30 cm SS/water shield; beam dump at 5.5<Z<6.5 m
- 60 cm diam Ti window separates He from vacuum



Decay Channel

Decay Channel (cont.)

- Covered by ~4.5 m steel and 0.5 m concrete shield for personnel access
- Contains LF solenoids
- 1.7 m steel for ground water protection



Shielding

- Neutron/gamma/proton flux profiles in the target area and decay channel (0<Z<16m) were generated to estimate dose rate and evaluate shield dimensions
- Criteria: 0.25 mr/h in the crane hall with beam on; beam power = 4 MW
- MCNPX cylindrical model

Dose Levels In Target Area	**Dose>1GeV**	**Dose<1GeV**	**Total Dose**
	7.4515E+11	9.7505E+11	1.7202E+12
	(mrem/h)	(mrem/h)	(mrem/h)
Tunnel Segment			
0.2 to 0.70	1.0005E+11	1.7095E+11	2.7099E+11
0.7 to 1.70	9.6226E+10	1.3606E+11	2.3228E+11
1.7 to 2.70	8.3777E+10	1.9958E+11	2.8335E+11
2.7 to 3.70	6.2515E+10	2.4726E+11	3.0977E+11
3.7 to 4.70	4.4562E+10	2.2039E+11	2.6495E+11
4.7 to 5.70	3.3549E+10	3.1250E+11	3.4605E+11
5.7 to 6.70	2.8647E+10	3.6626E+11	3.9491E+11
6.7 to 7.70	2.3574E+10	1.3264E+11	1.5621E+11
7.7 to 8.70	1.9190E+10	7.6736E+10	9.5926E+10
8.7 to 9.70	1.5758E+10	5.3156E+10	6.8914E+10
9.7 to 10.70	1.3255E+10	3.8942E+10	5.2196E+10
10.7 to 11.70	1.1229E+10	2.9572E+10	4.0801E+10
11.7 to 12.70	9.7006E+09	2.2883E+10	3.2584E+10
12.7 to 13.70	8.4020E+09	1.8354E+10	2.6756E+10
13.7 to 16.00	1.1923E+10	2.2099E+10	3.4022E+10

Shielding (cont.)

Criteria	Distance Downstream From Target (m)					
	3 to 5	5 to 7	7 to 9	9 to 11	11 to 13	13 to 15
	Steel Thickness (ft) / Concrete Thickness (ft)					
Minimum Total Thickness	14.8/1.0	14.8/1.4	14.2/0.9	13.9/1.0	13.1/1.6	14.1/1.0
Minimum Steel Thickness	14.2/2.0	14.8/1.4	12.8/3.4	11.8/4.4	11.5/4.7	12.1/4.1

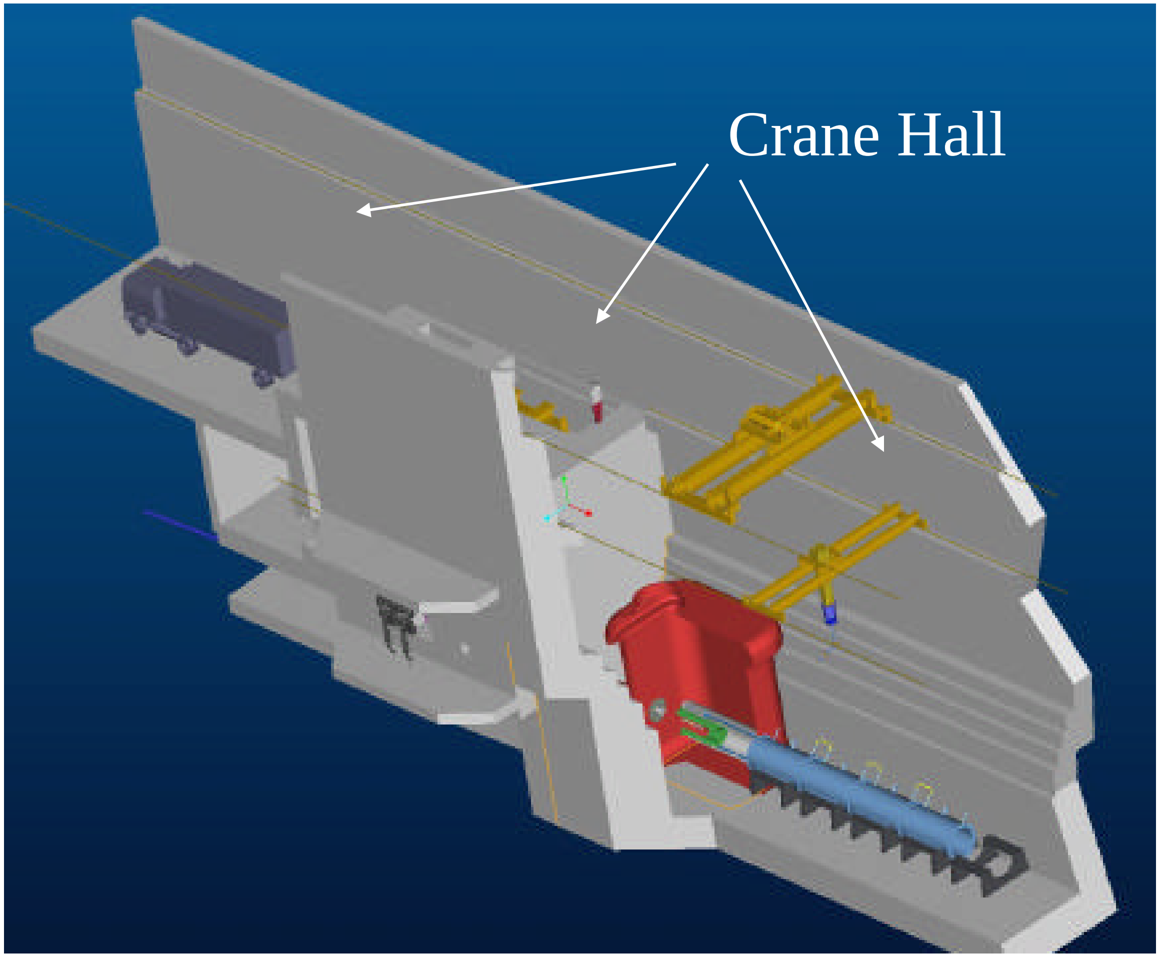
Shield (cont.)

- A high neutron/gamma flux will be present along the length of the decay channel (and beyond !)

	Total Neutron Flux		Total Gamma Flux	
Segment	**all protons**	**terminated p.**	**all protons**	**terminated p.**
(cm to cm)	(n/cm**2/s)	(n/cm**2/s)	(g/cm**2/s)	(g/cm**2/s)
target	9.6911e+12	9.6495e+12	2.9729e+13	2.9731e+13
20 to 70	1.8919e+12	1.8818e+12	4.7647e+12	4.7907e+12
70 to 170	1.5281e+12	1.5206e+12	3.1056e+12	3.1449e+12
170 to 270	2.0809e+12	2.0988e+12	3.3005e+12	3.3192e+12
270 to 370	2.5212e+12	2.4968e+12	3.7693e+12	3.7820e+12
370 to 470	2.2949e+12	2.0483e+12	3.4240e+12	3.3310e+12
470 to 570	3.1645e+12	1.1266e+12	3.7925e+12	2.4159e+12
570 to 670	3.6004e+12	5.4587e+11	4.5052e+12	1.5945e+12
670 to 770	1.4011e+12	4.7507e+11	2.3729e+12	1.2952e+12
770 to 870	7.9235e+11	4.7067e+11	1.5967e+12	1.1328e+12
870 to 970	5.3975e+11	3.8577e+11	1.1962e+12	9.2990e+11
970 to 1070	3.9134e+11	2.9575e+11	9.3197e+11	7.5742e+11
1070 to 1170	2.9506e+11	2.3312e+11	7.4797e+11	6.3161e+11
1170 to 1270	2.2796e+11	1.8900e+11	6.1290e+11	5.3764e+11
1270 to 1370	1.8210e+11	1.5578e+11	5.1870e+11	4.4537e+11
1370 to 1600	1.2125e+11	1.0064e+11	3.8147e+11	3.3290e+11

Crane Hall and Remote Handling

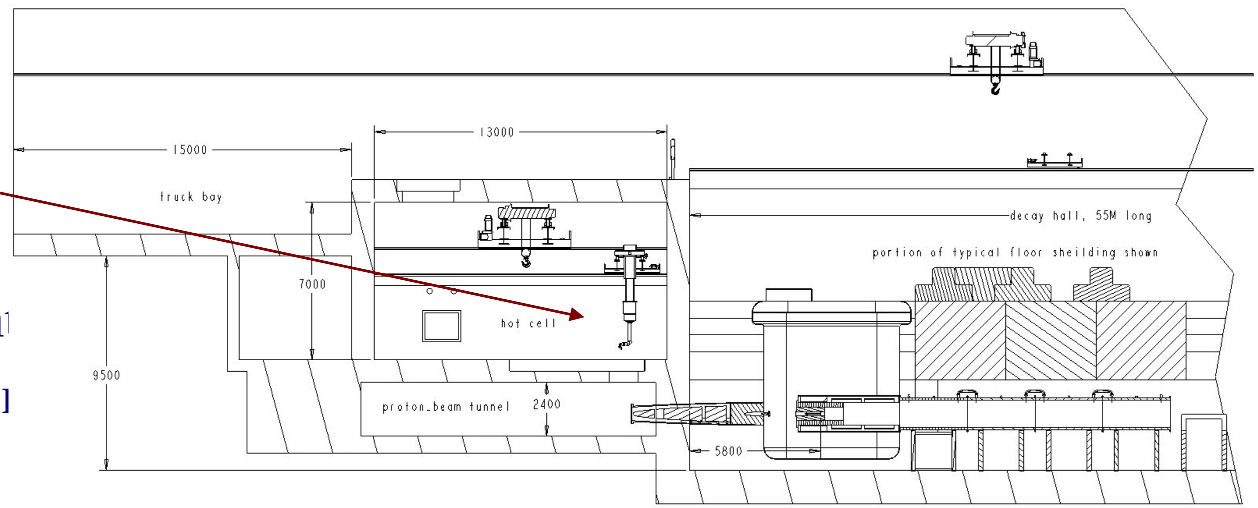
- Crane Hall
  - 12 m above floor level
  - 80 m length
  - 40 ton crane
  - bridge mounted manipulator
  - removable shield slabs (not shown)



Muon Collaboration

Crane Hall and Remote Handling (cont.)

- Hot Cell
  - 20 ton crane
  - bridge manipula
  - wall manipulato
  - CCTV, …



Component	Weight (lbs)	Size (m)
HF Cryostat	72,500	1.5 dia x 4.2
HF S/C Coil	18,000	1.5 dia x 1.2
Tungsten Shield Module	44,000	1.0 dia x 4.0
LF Cryostat/Steel Shield	44,000	1.3 dia x 4.0
Steel Shield Slabs	72,000	0.4 x 1.0 x 3.0
Vert. Steel Shield Blocks	28,000	0.6 x 1.2 x 2.0

Table of Component Sizes and Weights

Cost Estimate

- No contingency!
- No overhead burdens!

Construction Costs	$K
CraneBay/Target Region/Decay Channel	23,596
Hot Cell	1,418
Truck Bay	470
Engineering/QA/Procurement	5,200
Subtotal	31,194
Equipment Costs	
Target Area (incl HF coils: $8,729K)	9,880
Crane Hall	663
Decay Channel (incl LF coils: $8,831K)	14,390
Hot Cell	1,259
Engineering/QA/Procurement	4,800
Subtotal	31,527
Target Support Facility Total Cost	62,721

Conclusions

- A conceptual design for the neutrino factory ***target support facility*** was completed
- Preliminary calculations demonstrate feasibility using a passively-cooled graphite target
- Near term and longer term R&D are proposed to address material survivability and design issues for the graphite target
- A concept design for high field and low field solenoids demonstrates feasibility of resistive/superconducting magnets that meet field-on-axis requirements (NHMFL)
- The facility arrangement is based on work done for the SNS